# METHODOLOGY TO COMPARE COSTS OF SANITATION OPTIONS FOR LOW-INCOME PERI-URBAN AREAS IN LUSAKA, ZAMBIA

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## Abstract

Urban slums and low-income peri-urban areas in developing countries are characterised by a lack of infrastructure. The absence of sustainable sanitation systems often leads to a high occurrence of water-borne diseases in these areas, especially during the rainy season. The overall cost of a sanitation system option is one of the factors which a municipality should use to decide on the sanitation system that should be implemented in a peri-urban area. This paper presents a methodology for cost comparisons of sanitation system options (a sanitation *system* consists of the household toilets, collection and transport of excreta, treatment and storage, and transport of sanitised excreta to reuse sites).

We used three low-income peri-urban areas in Lusaka, Zambia, to demonstrate our proposed methodology, which consists of: short-listing suitable options by applying relevant selection criteria on a range of available options; developing concept designs for the short-listed options; using basic equations proposed in this paper to estimate capital and operating costs; and comparing NPV values of options. The population density in the three peri-urban areas ranges from 104 to 244 people per hectare. Unlined pit latrines are the most common form of sanitation, even though drilled boreholes and shallow wells are used as sources for drinking water in the same areas.

Based on our four selection criteria (no groundwater pollution, no use of water for transporting the waste, waste sanitisation and low costs), we have short-listed two options which meet most or all of the criteria: A conventional low-cost option (VIP latrines with downstream processing) and an ecological sanitation option (urine-diversion dehydrating (UDD) toilets with downstream processing). The concept designs for both options are based on the entire peri-urban population in Lusaka of approx. 1.23 million people, and on the assumption that 12 residents who live on the same would have to share one toilet.

The capital cost of one single vault UDD toilet in the peri-urban areas of Lusaka was estimated to be € 371 (including two 200-L plastic barrels for urine storage), compared to € 348 for one VIP toilet. The paper details the assumptions used to create a set of default model input parameters which are used in the cost equations. Based on this basic financial analysis, we found the following indicative figures for the ecological sanitation (ecosan) option: capital cost of € 48 million for 1.23 million people (or € 39 per capita); € 2.6 million per year in annual operating costs (or € 2.1 per year per capita).

Both options have similar NPV values, which shows that they are difficult to differentiate based on cost alone. The ecosan option has additional benefits compared to the conventional VIP latrine-based option, such as no pollution of groundwater. Urine transport and storage are significant contributors to the capital and operating costs of the ecosan option, and ways to reduce these costs need to be investigated further. The financial model allows examination of the relative contributions of the different components to the overall cost of the sanitation system.

**Keywords**: Cost estimates, NPV, Millennium Development Goals, groundwater, ecological sanitation, ecosan, VIP latrine, UDD toilet, financial model, reuse

## Introduction

### Background

As a consequence of the rapid urbanisation process in many developing countries, communities of very poor people are now living in the inner city or on the edge of those rapidly growing cities. These urban slums and low-income peri-urban areas are characterised by a lack of infrastructure such as access for vehicles and pedestrians, storm water drainage, water and sanitation services.

Provision of water and sanitation services for urban low-income areas, which is required to ensure public health, is particularly challenging for reasons such as insecure tenure, lack of political will, financing, cost recovery and choice of technical options. If municipalities and commercial utilities have to provide low-cost sanitation to peri-urban areas, which technology should they select: Conventional water-borne sanitation with sewers, conventional on-site sanitation (pit latrines, septic tanks) or ecological sanitation (e.g. urine-diversion dehydrating toilets)?

In this paper, we propose a methodology for comparing costs of sanitation options, consisting of the following six steps:

1. Analyse existing sanitation situation (we used three peri-urban areas in Lusaka as an example).
2. Define possible sanitation options and selection criteria.
3. Short-list a small number of options (two in our case) based on the selection criteria.
4. Prepare concept designs for the short-listed options.
5. Prepare cost estimates based on the concept designs, using basic cost equations proposed in this paper.
6. Compare results based on overall cost (Net Present Value) and other sustainability factors (other sustainability factors are only touched upon in this paper).

### Description of three peri-urban areas in Lusaka

Lusaka is the capital of Zambia in Southern Africa with a population of approximately 2 million in 2005 (annual growth rate of 3.5 % p.a. (CSO, 2003)); of which approximately 1.23 million people live in low-income unplanned peri-urban areas (GKW, 2005). The water supply service in the peri-urban areas of Lusaka is rudimentary, and sanitation service provision by the Lusaka City Council to those areas is almost none existent.

We selected three typical peri-urban areas (Bauleni, Chawama and John Laing) to collect baseline information for the subsequent options development. The fieldwork was carried out in Lusaka from November to December 2005 and is described in detail in Mayumbelo (2006). Field observations and informal discussions were used to investigate the current water and sanitation practices, state of the infrastructure and residents' health with respect to water-borne diseases.

Table 1 below summarises key characteristics of the three study areas. John Laing is the largest area but has yet to be legally recognised as a residential area by the municipality. Table 2 summarises the key research findings with regards to sanitation and water aspects for the three areas.

*Table 1 Key characteristics of Bauleni, Chawama and John Laing peri-urban areas (GKW (2005) and own data marked with *)*

| **Characteristic** | **Bauleni** | **Chawama** | **John Laing** |
|---|---|---|---|
| Approximate population | 26,000 | 68,000 | 82,000 |
| Number of plots | 2,790 | 7,608 | 9,638 |
| Number of households | 6,166 | 8,179 | 15,806 |
| Typical number of households per plot * | 2 | 3 | 4 |
| Approx. population density in people per hectare * | 104 | 244 | 160 |
| Expenditure on water as % of household income * | 0.7 to 5% (for all three areas) | | |
| Legal status | Recognised by municipality | | In process of recognition |
| Frequency of outbreaks of water-borne diseases (dysentery or other diarrhoea) * | Endemic (for all three areas) | | |

Sanitation provision in the peri-urban areas is generally left to the initiative of the residents who mostly use unlined pit latrines that they dig within their plot boundaries. The pits are covered with soil once they are full. The liquid fraction percolates into the ground and ultimately reaches the groundwater. The groundwater table ranges from low (approx. 30 m) to high (approx. 1 m). Karstic features of the geological formations underlying Lusaka make it complicated to predict in which direction and at what velocity groundwater will flow, and makes it difficult to dig new pits (see Figure 1).

Many residents in Chawama and John Laing use hand dug shallow wells as a source of drinking water (see Figure 2). This practice can be detrimental to their health since the groundwater quality in Lusaka fluctuates seasonally: it tends to deteriorate during the rainy season when pollution and recharge occurs due to pit latrines and the presence of preferential fast flow mechanisms in the karstic rock formations (Nkuwa, 2002). This problem is one of the causes of recurrent outbreaks of waterborne diseases in Zambia's peri-urban areas (Mayumbelo, 2006). It is in fact a general problem for many areas in sub-Saharan Africa with shallow urban groundwater, where the increase in diarrhea incidents in the rainy season can be attributed to pit latrines in peri-urban areas (Lerner, 2004).

*Figure 1 Raised pit latrine in the peri-urban area John Laing (rocky ground makes it difficult to dig pits).*

*Figure 2 Hand-dug shallow well near a pit latrine (background) in the peri-urban area John Laing.*

*Table 2 Summary of sanitation and water aspects for three peri-urban areas in Lusaka, Zambia*

| Aspect | Bauleni | Chawama | John Laing |
|---|---|---|---|
| Main sanitation practice - types of toilets | Unlined pit latrine (see Figure 1) | • Unlined pit latrine<br>• Water-flush toilet and septic tank with soak-away<br>• Use of plastic bags for defecation ("flying toilets") | • Unlined pit latrine<br>• Use of plastic bags for defecation |
| Greywater disposal method | • Disposed in road drains<br>• Soaked around point of discharge | | |
| Ownership of toilet | Usage of toilet is commonly shared by all tenants on the plot (average of 12 people) but officially the landlord owns the toilet structure | | |
| Problems identified by users with current practice | • Odour<br>• Breeding ground for flies and other vectors | • Frequent collapsing of pits<br>• Rocky ground makes it difficult to dig new pits | • Pollution of shallow wells<br>• Low water table |
| Status of sanitation infrastructure | Satisfactory to poor | | Poor |
| Residents without toilets[1] | 5% | 3% | 21% |
| Main drinking water sources | Drilled deep boreholes within Bauleni | Drilled deep boreholes within Chawama, and supply from Lusaka Water and Sewerage Company (LSWC) central network | One drilled deep borehole and supply from a small extension of LWSC central network |
| Alternative drinking water sources | None | Shallow hand dug wells (see Figure 2) | |
| Financing of sanitation service | Constructed by tenants or landlords, operated and maintained by tenants; costs vary as some residents may abandon a full toilet while others attempt to have it emptied (manually or by vacuum tanker) | | |

## Sanitation system options for peri-urban areas in Lusaka

### Options short-listing procedure

We advocate applying a "systems approach" to sanitation and as such, five major parts of the sanitation system ought to be distinguished (Figure 3):

- Part A: Household toilets
- Part B: Collection and transport of excreta from households to treatment site
- Part C: Treatment and storage of excreta at (semi-) centralised location
- Part D: Transport of sanitised excreta from treatment site to agricultural fields
- Part E: Reuse of excreta in agriculture (sale of fertiliser)

[1] People who use their neighbour's toilet or use toilets at bars/markets or use plastic bags (GKW, 2005).

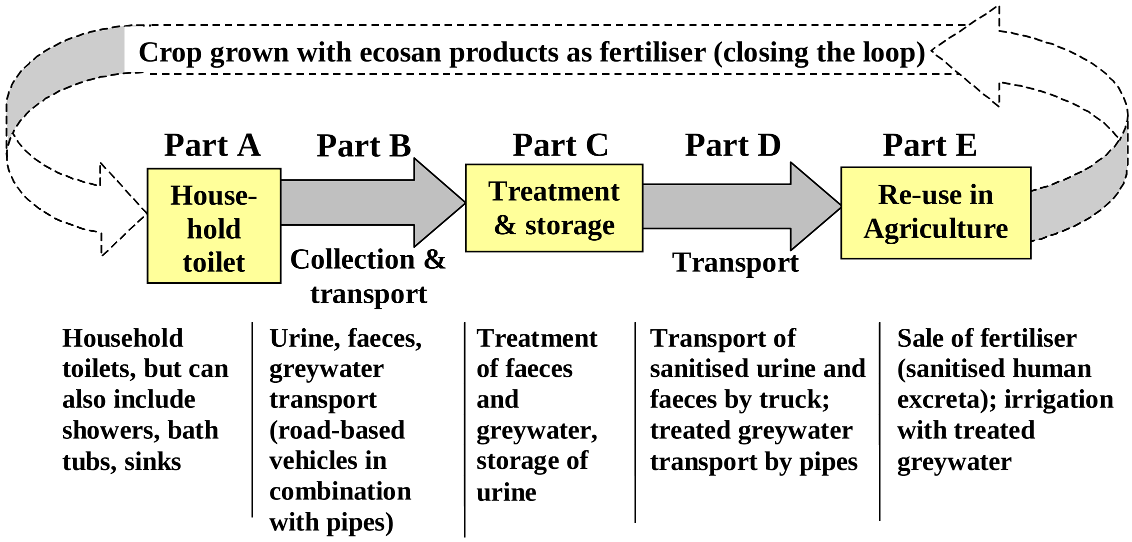


*Figure 3 Sanitation system components which need to be costed (dashed arrows are not costed). In this paper, the greywater management system is excluded from the analysis.*

For rural areas, the distances between Part A and Part E are very short, and they may therefore have a negligible impact on the overall cost. But for urban situations, Part B to D may have significant cost implications. Another consideration is that whilst Part A can be designed for individual households, Parts B to E should be designed to cover a number of households to achieve economies of scale.

We considered six broad sanitation options, which are schematically presented in Figure 4. Each of the six options is meant to cover the entire system (Part A to E). Options 1 to 5 are well known conventional sanitation options, whereas Option 6 is a relatively unknown ecological sanitation (ecosan) option, which is described in more detail below.

Ecosan is a new paradigm in sanitation which aims to enable safe reuse of sanitised excreta (Winblad and Simpson-Hébert, 2004) and be sustainable in all aspects. The nitrogen, phosphorus and organic matter in sanitised urine and faeces can be used in agriculture as a fertiliser and soil conditioner, respectively. This aspect is particularly important for poor people living in areas of nutrient-depleted soils in sub-Saharan Africa who cannot afford to purchase artificial inorganic fertiliser. Ecosan also eliminates the threat of groundwater pollution, unlike conventional on-site sanitation, and can typically be implemented at much lower costs than conventional water borne sewers (UNEP, 2004).

Ecosan interventions also have the potential to contribute to a whole range of Millennium Development Goals (Millennium-Project (2005), Rosemarin (2003), von Münch *et al.* (2006)), e.g. those related to basic sanitation provision, improvement of lives of slum dwellers, reduction of hunger and extreme poverty and reduced child mortality. Higher agricultural yields of fields fertilised with ecosan products can lead to a lower incidence of malnutrition and hence lower levels of morbidity.

The urine-diversion dehydrating (UDD) toilet is a toilet type that can be used within the ecosan approach. It separates the urine and faeces during defecation, and the two substances are stored and treated separately from each other (GTZ, 2007). The faeces are air dried in a ventilated single vault or double vault configuration (the second vault is used once the first vault is full), with the aim to achieve pathogen kill and volume reduction. The single vault system is selected here because of its lower investment costs. Its main disadvantage is that some of the faeces are still fresh when the vault is being emptied; the associated health risk can be managed for example by ongoing hygiene education programmes for the workers who empty the toilet vault after one year (Moilwa and Wilkinson, 2006).

We selected UDD toilets as the most suitable technology out of the large range of “wet” and “dry” ecosan technology options for Part A, mainly because of the unreliable water supply in peri-urban areas and because of the simplicity to operate these types of toilets (compared to composting toilets). UDD toilets are also resilient to floods, there is no contact of fresh excreta with groundwater, and the toilets can be located on any level inside the house. The dried faecal matter from a UDD toilet is less offensive and odorous than faecal sludge from pit latrines because faeces are not combined with urine or water.

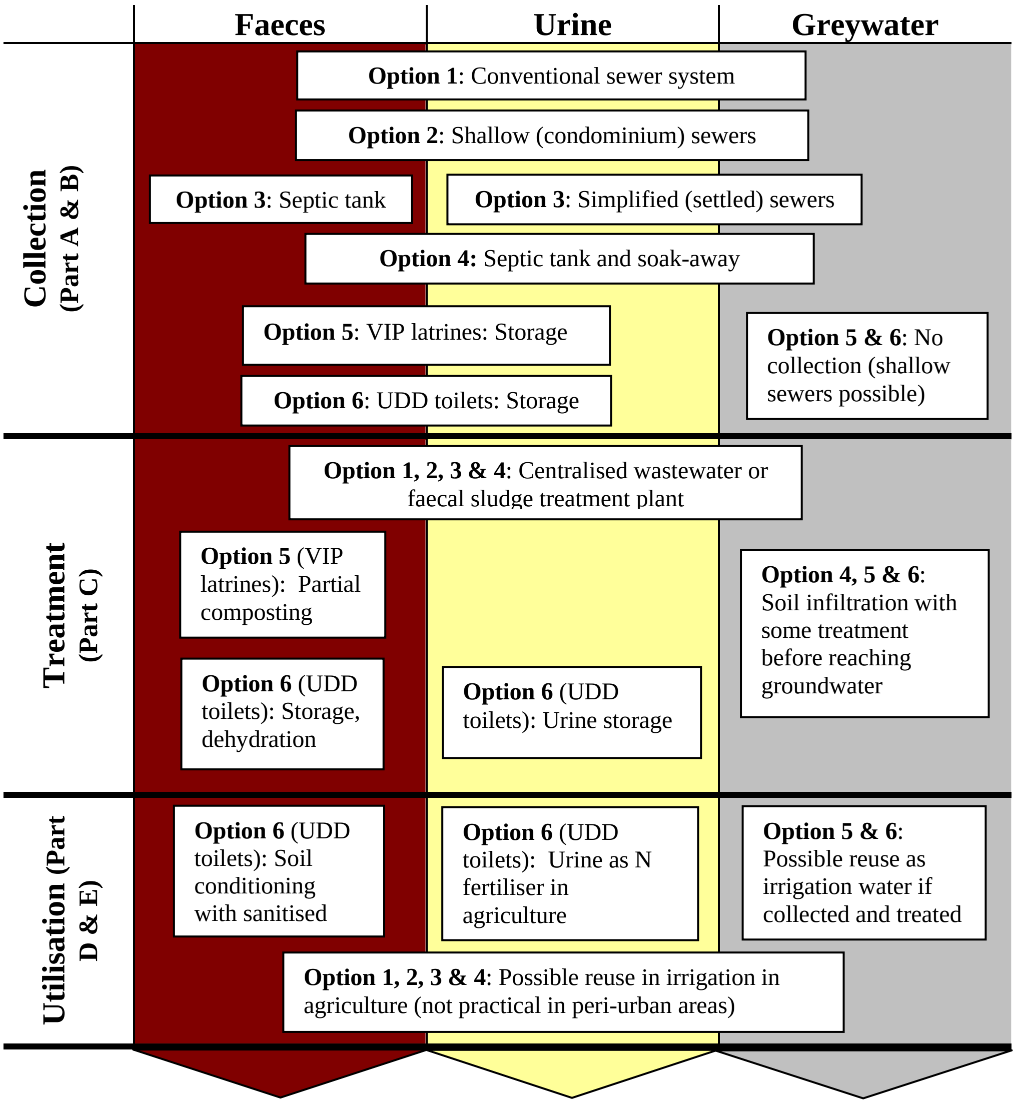


*Figure 4 Sanitation options for peri-urban areas of Lusaka. Options 1-4 include water-flush toilets, whereas Options 5 and 6 use waterless toilets (VIP = Ventilated Improved Pit). All options include downstream processing of the excreta. Greywater management not included in cost estimate.*

In order to select the most sustainable sanitation option, we need to consider sustainability criteria. Based on the approach presented by Kvarnström and af Petersens (2004), we applied the following four selection criteria:

1. Should not pollute groundwater, since shallow wells are being used as a drinking water source;
2. Should not require water for transporting waste (poor water supply levels in peri-urban areas);
3. Should sanitise the waste to destroy pathogens to protect public health; and
4. Have low capital, operation and maintenance costs to be financially sustainable.

Options 1 to 4 (shown in Figure 4) are discarded because they do not meet the selection criteria 2 and 4. Especially Option 1 (conventional sewer system) is comparatively expensive and requires a high level of institutional capacity and skilled work force.

Of the six options considered, the only option that satisfies all the selection criteria is Option 6: “UDD toilets with downstream processing”. Option 5 (“VIP latrines with downstream processing”) does not meet the first selection criterion: with the ground conditions such as in Lusaka, any pit latrine can contribute to groundwater pollution (pits are designed to allow infiltration of liquid; a “lined pit latrine” only has lining at the top part of the hole to stabilise it).

In general, pit latrines are not appropriate when the groundwater table is high and groundwater is used for drinking water, the ground is underlain by pervious rock (e.g. karst geology) or rock that is difficult to excavate, the area has a potential for flooding, or the population density is high and the space to dig new pits is therefore limited (or no means to safely empty full pits and to treat faecal sludge).

Even though Option 5 does not meet the first selection criterion, it is nevertheless included in the cost analysis in order to test the common perception that an ecosan option (Option 6) is more expensive than a conventional low-cost on-site sanitation option (Option 5).

**Concept designs of two short-listed options**

The concept designs of the two short-listed options are summarised in Table 3 below. They are based on the entire peri-urban population in Lusaka of 1.23 million people, because certain components (e.g treatment plant, vacuum tankers or trucks) are more economical at a larger scale. One toilet would be built per plot, and each toilet would be shared by three four-member households.

As shown in Table 3, our concept design for Option 6 includes a centralised storage facility for the dried faecal matter and urine. Other treatment options for the faecal matter could include:

- Co-composting with organic waste (as assumed for Option 5);
- Burial of the faecal matter in the ground provided the groundwater table is very low and precipitation is not that heavy and frequent (Guness *et al.*, 2006);
- Direct application of the faecal matter from the vaults in agricultural fields for restricted crops (such as fodder for animals or ornamental plants); or
- Burial of the faecal matter in shallow pits on which fruit trees are planted.

The fertiliser produced from either option could be used in agriculture or in public gardens, parks, potted flowers or potted plants. It is likely that the solid fertiliser produced in Option

6 is of higher quality than the compost produced in Option 5 because the former is less contaminated with other substances and has a higher nitrogen content (no leaching of nitrogen into the ground). We used a conservative estimate for the sales price of compost or solid fertiliser in our calculations (€ 2 per ton). Others have reported approximately € 28 per ton for compost made from organic solid waste (Rothenberger *et al.*, 2006) and € 22 per ton for compost made from faecal sludge and organic solid waste (Vodounhessi and von Münch, 2006).

The land required to absorb all nitrogen in the excreta is approximately 39,000 hectare for Option 6 (based on 5.7 kg nitrogen excreted per person per year and an application rate of 180 kgN/ha/yr. for maize (Jönsson *et al*., 2004). Excreta collected from Option 5 could only fertilise a smaller area because nitrogen of the urine will seep into the ground at the location of the VIP latrine. The total area of Lusaka province is 2,200,000 hectare (CSO, 2003) and Lusaka City itself is approximately 36,000 hectares. Hence, the area of 39,000 hectare which would have to be set aside for (urban) agriculture represents about 2% of the total Lusaka province area.

*Table 3 Summary of concept design for short-listed options (for Lusaka's peri-urban population of 1.23 million people)*

| | **Items which have an impact on capital costs** | | **Items which have an impact on operating costs** | |
|---|---|---|---|---|
| | **Option 5 (VIP + processing)** | **Option 6 (UDD toilets + processing)** | **Option 5 (VIP + processing)** | **Option 6 (UDD toilets + processing)** |
| Part A Household toilets | VIP toilets (102,400 toilets), first 1.2 m of pit is lined[a] | Single vault UDD toilets (102,400 toilets), designed to fill vault in one year; two 200 L plastic barrels per toilet for urine storage | None | None (sand, soil or ash as additive to faeces chamber is available at no or negligible cost |
| Part B Collection and transport of excreta | 16 vacuum tankers to transport the faecal sludge | Transport vehicles (see also Table 7):<br>• 2 open trucks with skips to transport dried faecal matter<br>• 28 open trucks to transport urine barrels (pick up once per week; 115 L per plot per week, from 12 people)[b] | Faecal sludge pumping from the pit once it is full, and transport (includes fuel, maintenance on trucks, salary overheads)[c] | Emptying of vaults (cost similar to garbage collection services). Transport cost for faecal matter and urine barrels; includes fuel, maintenance on trucks, salary, overheads. |
| Part C Treatment and storage of excreta | One faecal sludge treatment plant consisting of settling tanks, drying beds, co-composting with organic solid waste and waste stabilisation ponds for faecal sludge liquor | No treatment required, only storage[d]:<br>• Dried faecal matter stored for 6 months on 2 m high piles on concrete slabs, covered with tarpaulin sheets during rainy season to avoid leaching of the nutrients<br>• Plastic urine storage tanks for 2 weeks storage to allow collection for re-use (415 plastic tanks of 57 $m^3$ each) | Staff labour for operating the faecal sludge treatment plant (use standard figure for cost of treatment by Lusaka Water and Sewage Company based on septic tank sludge, in €/$m^3$). | Assume five workers managing the incoming and outgoing flows of material. |
| Part D Transport of san. excreta | Open trucks could be used but they are not included in cost estimate because we assume that the farmers who buy the fertiliser will organise the transport. Farmers will also need further urine storage of some form because nitrogen fertilisation is not carried out all year round; storage in the ground (soil) may be an option in some cases. | | | |
| Part E: Reuse in agriculture | No capital cost items (buying of land is not included) | | Sale of treated sludge (compost) | Sale of ecosan products (sanitised faeces and urine) |

**Notes for Table 3:**

[a] First 1.2 metres of pit is lined with bricks and mortar to prevent pit from collapsing (remainder of the pit is porous to allow liquid to infiltrate into soil).

[b] Number of trucks is based on 40 urine barrels per load, two hours return trip, 12 working hours per day to transport the mass flows of Part B (see Table 7).

[c] For faecal sludge pumping to work, water has to be jetted into the pit to liquefy the faecal sludge sufficiently.

[d] The secondary treatment of faeces (further storage and drying) would cause further pathogen die-off and therefore reduce the risk of disease transmission.

## Financial model for short-listed sanitation options

Various authors have published cost estimates for sanitation systems (e.g. Hutton and Haller (2004), Rockström *et al.* (2005)) but the costs are often difficult to compare, e.g. because they only include Part A of the sanitation system, or only the first year of operation. A useful tool for a basic financial comparison of sanitation options is the Net Present Value (NPV) of the capital and yearly operation and maintenance costs of the entire sanitation system (Part A to E in Figure 3). The option with the lowest absolute value for NPV is the most attractive from a financial point of view.

We used a discount rate of 12% (equivalent to government borrowing rate) and a time period of 10 years in our NPV analysis; during this time frame the options considered would not require replacements or major repairs. Where possible, we have formulated general cost equations for the financial model. The input parameters for the financial model can be varied by the user of the model and should be verified for a specific application of the model.

### Capital costs

Capital costs for both options are summarised in Table 5, and the costs for Part A are explained in more detail below. The cost of a toilet increases with increasing volume of its "substructure", i.e. the pit or vault. The minimum volume of the substructure is calculated by Eqn. (1) below (parameter descriptions and values are provided in Table 6).

$$V_{sub,min} = p_f \cdot N_{Lsk} \cdot T_d \qquad \text{Eqn. (1)}$$

The substructure volume of the toilets in Option 5 is much larger than the substructure volume of toilets in Option 6 because of the longer time period between desludging events assumed for Option 5, due to access restrictions for the vacuum tankers (see parameter $T_d$ in Table 6). - The capital cost for one toilet of Part A of Option 5 (see Table 4) consists of pit excavation, pit lining (to 1.2 m depth), cover slab, superstructure and a vent pipe. For Option 6, the cost items for one UDD toilet are a floor slab, faeces vault, cover slab, superstructure, vent pipe, two 200 L plastic barrels for urine storage, a urine-diversion squatting pan and a bucket for sand or ash. The cost of a simple superstructure is identical for the two options. Details of the cost estimate (bill of quantities) are provided in Mayumbelo (2006).

*Table 4 Capital cost of one toilet (for Part A); includes material and labour cost for superstructure and substructure (pit for Option 5, vault for Option 6); assuming cross-sectional area of 1.5 $m^2$ for both options, and unused pit depth (freeboard) of 0.6 m for Option 5. Zero freeboard assumed for Option 6.*

| **Toilet type** | **Minimum volume of substructure from Eqn. (1) ($m^3$)** | **Total volume of substructure ($m^3$)** | **Total depth of substructure (m)** | **Cost (€)** |
|---|---|---|---|---|
| VIP toilet with first 1.2 m of pit side walls being lined (for Option 5) | 4.2 | 5.1 | 3.4 | 348 |
| Single vault UDD toilet (for Option 6) | 0.6 | 0.6 | 0.4 | 371 |
| *Comparison costs from others:* | | | | |
| VIP toilet in Uganda (Niwigaba *et al*., 2006) | | | | 106 - 211 |
| Double vault UDD toilet in Uganda (Niwigaba *et al*., 2006) | | | | 296 - 464 |
| Double vault UDD toilet in South Africa[2] | | | ~ 0.5 | 632 |

[2] The municipality of eThekwini (Durban) in South Africa installed 37,000 double vault UDD toilets in 2005 at this cost (personal communication: Teddy Gounden, Manager Community Education, e-Thekwini Water and Sanitation, Durban, South Africa).

*Table 5 Capital costs for the short-listed sanitation options for Lusaka's peri-urban population of 1.23 million (in € unless otherwise indicated) – based on concept design in Table 3.*

| Part | | Option 5 (VIP toilets + processing) | Option 6 (UDD toilets + processing) | Comments |
|---|---|---|---|---|
| Part A | Toilets with sub- and superstructure | 35,650,000 | 38,010,000 | Based on Table 4, for 102,400 toilets |
| Part B | Trucks to transport the excreta from toilets to treatment site | 1,760,000 | 1,500,000 | Option 5: Cost of one new vacuum truck taken to be € 110,000<br>Option 6: Cost of one second-hand open truck: € 50,000 (Vodounhessi and von Münch, 2006) |
| Part C | Faecal sludge treatment plant | 1,309,300 | 0 | Based on a similar plant design for Kumasi, Ghana (Vodounhessi and von Münch, 2006); cost of land not included |
| | Dried faecal matter storage | 0 | 276,000 | Mayumbelo (2006); cost of land not included |
| | Urine storage tanks | 0 | 8,109,000 | Mayumbelo (2006) |
| | *Subtotal for Part C* | *1,309,300* | *8,385,000* | |
| Part D | Trucks to transport the sanitised excreta | 0 | 0 | Transport burden and urine storage costs shifted to farmers |
| Part E | Sale of fertiliser / ecosan products | 0 | 0 | No capital cost item |
| Total capital costs (million €) | | **39** | **48** | |
| Total capital cost per capita (€/cap) | | **31** | **39** | |

## Operating costs

The equations used in the financial model to predict the operating costs of Part B, C and E ($C_{Part\ i,\ op}$) are shown below (symbol names, parameter values and units are provided in Table 6). The operating costs of both options are summarised in Table 8.

$$C_{Part\ B,\ op} = F_d \cdot N_{Lsk} / N_{P/t} \cdot C_{ve} + (F_{w,1} \cdot p_f + p_{urine}) \cdot N_{Lsk} \cdot C_{t,1} / V_{tv} \quad \text{Eqn. (2)}$$

$$C_{Part\ C,\ op} = F_{w,1} \cdot p_f \cdot N_{Lsk} \cdot C_{tr,s} + N_w \cdot C_{w,a} \quad \text{Eqn. (3)}$$

$$C_{Part\ E,\ op} = - \rho_{comp} \cdot F_{w,2} \cdot F_{w,1} \cdot p_f \cdot N_{Lsk} \cdot C_{comp} - p_{urine} \cdot N_{Lsk} \cdot C_{urine} \quad \text{Eqn. (4)}$$

The default model parameter values shown in Table 6 are the result of a simplistic analysis, which does not take into account the fact that the residents will spend part of their day outside the peri-urban areas, the lower excreta production rates of children, nor the weight of the material added after defecation to cover the material and absorb moisture. - The quantities of excreta to be moved in the two transport steps (Part B and Part D) are shown in Table 7. A summary of the financial model output values is provided in Table 9.

*Table 6 Default input parameter values for financial model (see Mayumbelo (2006) for further background information)*

| Parameter | Symbol | Unit | Option 5 (VIP + processing) | Option 6 (UDD + processing) | Further explanations |
|---|---|---|---|---|---|
| Sales prices of compost or dried faecal matter | $C_{comp}$ | €/ton | 2 | 2 | Current price for biosolids from WWTP in Lusaka |
| Cost of using a transport vehicle for transport from plot to treatment site | $C_{t,1}$ | €/event | 72 | 60 | Independent of travel distance (current practice in Lusaka); includes pit emptying for Option 5 |
| Cost of treating faecal sludge | $C_{tr,s}$ | €/m$^3$ | 2.4 | 0 | Based on current charge of LWSC for Option 5 |
| Sales price for urine | $C_{urine}$ | €/m$^3$ | 0 | 0.75 | Nutrients worth € 0.15 per 20 L jerry can (Dagerskog, 2006); assume can only sell at one tenth of theoretical value. |
| Cost of vault emptying, per event | $C_{ve}$ | €/event | 0 | 5 | Assuming 30 minutes, and € 10 per hour salary cost |
| Annual cost of a general worker | $C_{w,a}$ | €/yr. | 0 | 4,300 | Typical salary for a general worker in Lusaka for Option 6 |
| Frequency of desludging or emptying | $F_d$ | 1/yr. | 0.2 | 1 | = 1 / $T_d$ |
| Factor to account for volume change in Part B | $F_{w,1}$ | - | 2 | 0.5[3] | Option 5: Increase due to necessary water jetting |
| Factor to account for water loss during treatment in Part C | $F_{w,2}$ | - | 0.1 | 0.5 | For Option 5: Compost yield from faecal sludge is about 0.1 ton/m$^3$ (Vodounhessi and von Münch, 2006). Option 6: some further drying will occur (total: $F_{w,1}$ x $F_{w,2}$ = 0.25) |
| Number of households per plot | $N_{hh/pl}$ | - | 3 | 3 | Table 1 |
| Number of people covered in the scheme | $N_{Lsk}$ | cap | 1,229,323 | | Design value (peri-urban population) |
| Number of people per household | $N_{p/hh}$ | - | 4 | 4 | Own estimate |
| Number of people per toilet | $N_{P/t}$ | - | 12 | 12 | = $N_{hh/pl}$ x $N_{p/hh}$ |
| Number of workers at the storage site | $N_w$ | - | 0 | 5 | Design value |
| Specific annual faecal sludge or faeces production | $p_f$ | m$^3$/cap/yr | 0.07 | 0.05 | Heinss *et al.* (1998) for Option 5; Jönsson *et al*. (2004) for Option 6 (faeces production at point of excretion) |
| Specific annual urine production | $p_{urine}$ | m$^3$/cap/yr | 0 | 0.5 | = 500 L/cap/year or 1.37 L/cap/d (Jönsson *et al*., 2004) |
| Density of compost or dried faecal matter | $\rho_{comp}$ | ton/m$^3$ | 1.2 | 1.2 | Own estimate |
| Time between desludging or emptying events | $T_d$ | years | 5 | 1 | Own design value |
| Volume of substructure (without freeboard) | $V_{sub,min}$ | m$^3$ | 4.2 | 0.6 | Equals sludge volume when pit or vault is full |
| Volume of transport vehicle | $V_{tv}$ | m$^3$ | 5 | 15 | Vacuum tanker in Option 5, skip on open truck in Option 6 |

[3] Conservative estimate since fresh faeces at excretion are about 80% water (Jönsson *et al*., 2004); total volume reduction factor could be as low as 0.2.

*Table 7 Quantities of excreta to be moved (based on 1.23 million people and calculated using adapted Eqn. (2) for Part B and adapted Eqn. (4) for Part D). Density of material in Part D as shown in Table 6 ($\rho_{comp}$))*

| **Transport step** | **Quantity parameter** | **Option 5 (VIP + processing)** | **Option 6 (UDD toilets + processing)** | |
|---|---|---|---|---|
| | | **Faecal sludge** | **Faecal matter** | **Urine**[a] |
| Part B | Volume ($m^3$/year) | 172,100 | 30,700 | 614,700 |
| Part D | Volume ($m^3$/year) | 17,200 | 15,400 | 614,700 |
| | Mass (tons/year) | 20,600 | 18,500 | 614,700 |

[a] Assumed that there are no evaporation losses and specific gravity of urine is 1.0.

*Table 8 Operating costs for the short-listed sanitation options for Lusaka's peri-urban population of 1.23 million (in €/yr. unless otherwise indicated) ) – based on concept design in Table 3.*

| **Part** | | **Option 5 (VIP toilets + processing)** | **Option 6 (UDD toilets + processing)** | **Comments** |
|---|---|---|---|---|
| Part A | Operation and maintenance costs for toilets | 0 | 0 | Robust structures requiring only cleaning; cost of additive for Option 6 negligible |
| Part B | Cost of removing faecal matter from vault | 0 | 512,000 | Option 5: included in next line item<br>Option 6: first part of Eqn. 2 |
| | Faecal sludge / faecal matter transport from plot to treatment plant / storage site | 2,478,000 | 123,000 | Second part of Eqn. 2 |
| | Transport of urine barrels from plot to storage site | 0 | 2,459,000 | Third part of Eqn. 2 |
| | *Subtotal for Part B* | *2,478,000* | *3,094,000* | |
| Part C | Treatment costs | 413,000 | 0 | First part of Eqn. 3 |
| | Staff labour at storage site | 0 | 21,000 | Second part of Eqn. 3 |
| | *Subtotal for Part C* | *413,000* | *21,000* | |
| Part D | Transport cost of sanitised excreta to user | 0 | 0 | Transport costs to be covered by farmers |
| Part E | Income from sale of treated sludge or faecal matter | -41,000 | -37,000 | First part of Eqn. 4 (note negative value since it is an income) |
| | Income from sale of urine | 0 | -461,000 | Second part of Eqn. 4 |
| | *Subtotal for Part E* | *-41,000* | *-498,000* | |
| Total operating costs (million €/yr) | | 2.9 | 2.6 | |
| Total operating costs per capita (€/cap/yr) | | 2.3 | 2.1 | |

*Table 9 Output parameter values from financial model for Lusaka's entire peri-urban population (1.23 million people); the lower the absolute value of NPV, the better.*

| Model output parameter | Option 5 (VIP toilets + processing) | Option 6 (UDD toilets + processing) |
|---|---|---|
| Total capital costs (million €) | 39 | 48 |
| Capital costs per capita (€/cap) | 31 | 39 |
| Total operating costs (million €/yr.) | 2.9 | 2.6 |
| Operating costs per capita (€/yr./cap) | 2.3 | 2.1 |
| Total NPV (million €), based on 12% discount rate and 10 years project lifetime | 16 | 15 |

**Discussion of cost estimates**

The following observations can be made regarding the capital costs:

- The accuracy of the cost estimate is expected to be ± 25% for a concept design of this nature. Hence, whilst the capital cost of Option 6 is higher than that of Option 5, this difference is not significant compared to the accuracy of the estimate.
- Part A (toilets) constitutes by far the largest contribution to the overall capital costs for both options. Hence the biggest potential for capital cost savings lies in Part A.
- The second biggest contributor to the costs of Option 6 is the urine storage facility. Urine storage has two purposes: (i) further pathogen kill (e.g. those pathogens that stem from cross-contamination with faeces), and (ii) holding urine while it is not needed by the farmers. Longer urine storage times reduce health risks but also increase capital costs. We used two weeks as a minimum time needed to buffer farmers' demand but clearly, the practicalities of this assumption need further consideration.

The following observations can be made regarding the operating costs:

- The operating costs are slightly lower for Option 6 than for Option 5, but the difference is not significant within the accuracy of the estimate.
- The largest contribution to the operating costs originates from Part B (excreta collection and transportation to treatment plant) for both options. The transport cost of the urine barrels is a potential hindrance to the adoption of Option 6. Transport in small-bore pipes, together with greywater, could be an alternative option in some cases but may be more capital cost intensive.
- The sale of urine has potential to generate a significant income due to its nitrogen and phosphorus content whilst being virtually pathogen-free. The achievable sales price for urine requires further investigations (a conservative sales price was used here).

When the entire sanitation system is considered, the NPV values of both options are close to each other. Hence, in the case of Lusaka, the ecosan option (Option 6) cannot be ruled out on cost, compared to the conventional VIP latrine-based option (Option 5).

## Conclusions

Because ecosan is still a relatively new approach to sanitation, many municipalities do not realise that it could be a viable and cost-effective alternative to sewer-based sanitation systems, septic tanks and pit latrines. Decision makers need adequate information regarding the costs of the entire sanitation system. Many previous publications that dealt with sanitation costs only provided the costs of the toilet without the accompanying downstream processing infrastructure, and annual operating costs.

We have developed basic equations to calculate:

- The minimum volume of the toilet's substructure; this has an impact on the capital cost of Part A (toilets);
- Operating costs of Part B (transport), Part C (treatment/storage) and Part E (sale of fertiliser)

The equations use a set of input parameters for which default values suitable for conditions similar to Lusaka are provided. The capital costs for Option 6 were found to be higher than for Option 5, whilst its annual operating costs and NPV value were slightly lower (but the differences were less than the expected accuracy of ± 25% for a concept design of this nature). The costs presented in this paper only give an indication of the situation and serve to illustrate our cost comparison methodology. Further work is needed to refine the detailed design of the options as well as the values of the model input parameters, which will also vary from country to country.

To improve public health in the peri-urban areas, it is necessary to have a sanitation system that is sustainable in all aspects, i.e. socially, technically, environmentally, institutionally and financially. This paper has focussed on the financial aspect of sanitation systems. Financial sustainability is only one aspect in the decision making process but from our analysis of the entire sanitation system, it is obvious that the proposed ecosan option is not only able to prevent groundwater pollution in densely populated areas, but is also cost competitive compared to the often used conventional low-cost sanitation option (VIP latrines with downstream processing).

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